Exergetic and Environmental Analyses of Turbojet Engine

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Abstract This study deals with exergetic and environmental analyses of turbojet engine used on the military training aircrafts. In the analysis, the engine data measured in the Engine Test Cell at First Air Maintenance and Factory Directorate of Turkish Air Forces in Eskisehir, Turkey are utilized. The exergy balance equations are derived for each component of the engine along with the overall the engine. Several thermodynamic parameters (the fuel exergy depletion ratio, the productivity lack ratio, the relative exergy consumption ratio, exergetic improvement potential, exergetic improvement potential ratio, relative exergetic improvement potential, exergetic fuel-product ratio, and sustainability index) are used to evaluate the performance of the engine and its main components (the air compressor, the combustion chamber, the gas turbine, the exhaust forward duct, the aft exhaust duct, and the mechanical shaft). Exergy losses and destructions are investigated to determine thermodynamic inefficiencies. The exergetic efficiency of the engine is determined to be 18.77%. The highest exergy destruction rate of 2921.01 kW in the engine occurs within the combustion chamber. The mechanical shaft of the engine has the maximum sustainability index of 100.65. An environmental analysis of the engine is also performed.

Keywords Turbojet engine · Exergy analysis · Exergy efficiency · Sustainability index · Environmental analysis

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Nomenclature

c_P	Specific heat capacity (kJ kg^{-1} K^{-1})
$\dot{E}x$	Exergy rate (kW)
$\dot{E}xIP$	Exergetic improvement potential (kW)
$\dot{E}xIPR$	Exergetic improvement potential rate ratio (%)
LHV	Lower heating value of fuel (kJ kg^{-1})
$\dot{m}$	Mass flow rate (kg s^{-1})
p	Pressure (kPa)
$R\dot{E}xIP$	Relative improvement potential rate (%)
SI	Sustainability index (–)
T	Temperature (K)
$\dot{W}$	Work rate or power (kW)

Greek Letters

α	Fuel exergy depletion ratio (%)
β	Productivity lack ratio in exergetic term (%)
χ	Relative exergy consumption ratio (%)
γ	Fuel exergy grade function
ψ	Exergy (second law) efficiency (%)

Subscripts

a	Air
AC	Air compressor
C	Consumption
CC	Combustion chamber
cg	Combustion gases
D	Destroyed, destruction
EAD	Exhaust aft duct
EFD	Exhaust forward duct
GT	Gas turbine
GTMS	Gas turbine mechanical shaft
in	Input
out	Output
P	Pressure
Pr	Product
ref	Reference

T	Temperature
TJE	Turbojet engine

Abbreviations

AC	Air compressor
EAD	Exhaust aft duct
EFD	Exhaust forward duct
CC	Combustion chamber
GT	Gas turbine
GTMS	Gas turbine mechanical shaft
TJE	Aircraft jet engine

1 Introduction

Using the energy of fuel to produce flights is the job of both the military and civil aviation propulsion system. The military aircraft is used to maximize aerodynamic performance, in which case it complies with some operational constraints and uses fuel less efficiently than an efficient aircraft. High-performance start-up, maximum performance climbing and retrofitting are significantly less fuel-efficient than driving performance [1]. For cost-effective and environmental-friendly aviation, system efficiency should be kept maximum, while minimizing cost and environmental impacts of aircraft engines. In order to achieve these objectives, the engine must be operated in optimum operating mode, the best quality fuel should be selected, the fuel consumption rate and the exergetic consumption (losses and destruction) rate should be reduced and the cost of capital should be diminished. In this context, thermodynamic exergy, exergoeconomic, sustainability, and environmental (exergoeconomic, environmental damage cost) analysis methods are used to evaluate the performance of aircraft engines [2]. The main objective of this study can be summarized as follows:

- Exergetic analyses of J69 turbojet engine used on the military training aircrafts.
- Environmental analyses of J69 turbojet engine used on the military training aircrafts.

The exergy balance equations derived for each component of the engine along with the overall the engine and exergoenvironomic balance equations are given below section.

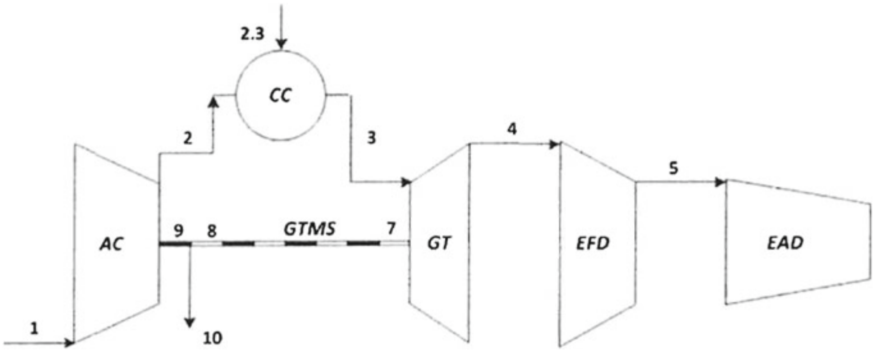

Fig. 1 Schematic of the investigated turbojet engine

2 Methodology

2.1 General Description of TJE with Afterburner

A schematic of the investigated TJE is given in (Fig. 1). This system consists of an air compressor (AC), a combustion chamber (CC), a gas turbine (GT), an exhaust forward duct (EFD), an exhaust aft duct (EAD), and a gas turbine mechanical shaft (GTMS).

2.2 Assumptions

In this study, the assumptions made are listed below:

- The TJE operates in a steady-state.
- The ideal gas principles are applied to air and combustion gas.
- The combustion reaction is complete.
- The changes in the kinetic exergy and potential exergy are assumed negligible.
- The temperature and pressure of dead state are 288.15 K and 99.85 kPa, respectively.
- The exergetic analyses are made on the lower heating value (LHV) basis of liquid JP-8 fuel.
- The chemical formula of jet fuel is assumed as $C_{12}H_{23}$.
- While the engine operates in military operation, air/fuel mass ratio is equal to 65.

2.3 The Exergy Equilibrium Equations

General exergy equilibrium equation is defined in Eq. (1) as under mentioned:

$$\sum\left(1-\frac{T_o}{T_k}\right)\dot{Q}_k-\dot{W}+\sum_{\text{in}}\dot{\text{E}}\text{x}_{\text{in}}-\sum_{\text{out}}\dot{\text{E}}\text{x}_{\text{out}}-\dot{\text{E}}\text{x}_{\text{D}}=0 \tag{1}$$

where $\dot{Q}_k$ represents the heat transfer rate through the boundary at temperature T_k at the location k, $\dot{W}$ is the work rate, $\dot{\text{E}}\text{x}$ is the exergy rate of stream, and $\dot{\text{E}}\text{x}_{\text{D}}$ is the exergy destruction rate.

The total exergy for a system can be given in Eq. (2) as under mentioned:

$$\dot{\text{E}}\text{x}=\dot{\text{E}}\text{x}_{kn}+\dot{\text{E}}\text{x}_{\text{pt}}+\dot{\text{E}}\text{x}_{\text{ph}}+\dot{\text{E}}\text{x}_{\text{ch}} \tag{2}$$

where the terms $\dot{\text{E}}\text{x}_{kn}$, $\dot{\text{E}}\text{x}_{\text{pt}}$, $\dot{\text{E}}\text{x}_{\text{ph}}$, and $\dot{\text{E}}\text{x}_{\text{ch}}$ denote the kinetic exergy, potential exergy, physical exergy, and chemical exergy, respectively. In the present study, the changes in the kinetic exergy and potential exergy within the system are assumed negligible.

The physical exergy for air and combustion gaseous with constant specific heat is obtained in Eq. (3) as under mentioned [3]:

$$\dot{\text{E}}\text{x}_{\text{ph}}=\dot{m}c_{\text{P}(T)}\left[T-T_o-T_o\ln\left(\frac{T}{T_o}\right)\right]+RT_o\left(\frac{P}{P_o}\right) \tag{3}$$

The chemical exergy of liquid fuels as C_aH_b on a unit mass basis can be determined in Eq. (4) as under mentioned:

$$\frac{\dot{\text{E}}\text{x}_{\text{ch},f}}{\dot{m}_f\text{LHV}_f}=\gamma_f\cong 1.04224+0.011925\frac{b}{a}-\frac{0.042}{a} \tag{4}$$

where γ_f denotes the liquid fuel exergy grade function. The chemical formula of jet fuel is assumed as $C_{12}H_{23}$. γ_f is calculated as 1.0596 for this fuel. The sum of fuel chemical exergy and the fuel physical exergy gives fuel energy in Eq. (5) as follows:

$$\dot{\text{E}}\text{x}_f=\left(\dot{\text{E}}\text{x}_{\text{ch}}+\dot{\text{E}}\text{x}_{\text{ph}}\right)_f \tag{5}$$

2.4 The Exergy Efficiency and Thermodynamic Performance Parameters

The exergy efficiency of the system or subsystems can be defined as the ratio of the exergy in outputs products to the exergy in inputs. The exergy efficiency of air compressor is obtained as under mentioned:

$$\psi = \frac{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{out}} - \dot{\mathrm{E}}\mathrm{x}_{\mathrm{in}}}{\dot{W}} \tag{6}$$

The exergy efficiencies of the n'th component of a system are calculated in Eq. (7) as under mentioned:

$$\psi = \frac{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{out}}}{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{in}}} \tag{7}$$

The exergy efficiency of whole system is obtained as under mentioned:

$$\psi_{\mathrm{SYS}} = \frac{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{P}}}{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{F}}} \tag{8}$$

The thermodynamic parameters such as the fuel depletion rate, relative irreversibility, and productivity lack, are used in evaluating the exergetic performance of the system [4]. These are given in Eqs. (9)–(16) as follows:

The fuel exergy depletion ratio is written as the ratio of the exergy consumption of n'th component to the fuel exergy rate input the TJE such as:

$$\alpha_j = \frac{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{C},j}}{\dot{\mathrm{E}}\mathrm{x}_f} \tag{9}$$

The productivity lack ratio is written as the ratio of the exergy consumption of n'th component to the exergy of products as:

$$\beta_j = \frac{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{C},j}}{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{P,TJE}}} \tag{10}$$

The relative exergy consumption ratio is defined as the ratio of the exergy consumption of n'th component to the exergy consumption of the TJE system as:

$$\chi_j = \frac{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{C},j}}{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{C,TJE}}} \tag{11}$$

Van Gool also stated that maximum improvement in the exergy efficiency for a process or system could be achieved when the exergy consumption is minimized. Consequently, he suggested that it is useful to employ the concept of an exergetic improvement potential when analyzing different processes, as applied by some investigators [5]. The exergetic improvement potential can be written as follows [2]:

$$\dot{\mathrm{E}}\mathrm{xI}\dot{\mathrm{P}}_j = (1 - \psi)\dot{\mathrm{E}}\mathrm{x}_{\mathrm{C},j} \tag{12}$$

The exergetic improvement potential ratio:

$$\dot{\mathrm{E}}\mathrm{xI}\dot{\mathrm{P}}\mathrm{R}_j = \frac{\dot{\mathrm{E}}\mathrm{xI}\dot{\mathrm{P}}_j}{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{D},j}} \tag{13}$$

The relative exergetic improvement potential:

$$\mathrm{R}\dot{\mathrm{E}}\mathrm{xI}\dot{\mathrm{P}}_j = \frac{\dot{\mathrm{E}}\mathrm{xI}\dot{\mathrm{P}}_j}{\dot{\mathrm{E}}\mathrm{xI}\dot{\mathrm{P}}_{\mathrm{tot}}} \tag{14}$$

Exergetic fuel-product ratio:

$$\mathrm{FPR}_{\mathrm{ex},j} = \frac{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{in},j}}{\dot{\mathrm{E}}\mathrm{x}_{\mathrm{out},j}} \tag{15}$$

Sustainability index:

$$\mathrm{SI}_j = \frac{1}{(1-\psi)} \tag{16}$$

2.5 The Specific Heat Capacity of Air and Combustion Gases

Combustion equilibrium equation for the engine is given as under mentioned:

$$\begin{aligned} &C_{12}H_{23} + 379.61(0.7748N_2 + 0.2059O_2 + 0.0003CO_2 + 0.019H_2O) \\ &\quad \rightarrow 12.11CO_2 + 18.71H_2O + 60.41O_2 + 294.12N_2 \end{aligned} \tag{17}$$

The specific heat capacity of the combustion gases:

$$c_{\mathrm{P,cg}}(T) = 0.91582 + \frac{0.01102}{10^2}T + \frac{0.01556}{10^5}T^2 - \frac{0.06724}{10^9}T^3 \tag{18}$$

The specific heat capacity of air is a function of temperature [6]:

$$c_{\mathrm{P,a}}(T) = 1.04841 - 0.000383719T + \frac{9.45378T^2}{10^7} - \frac{5.49031T^3}{10^{10}} + \frac{7.92981T^4}{10^{14}} \tag{19}$$

2.6 The Exergy Equilibrium Equations of the TJE and Its Components

The exergy equilibrium equations for the TJE and its primary segments are shown in Eqs. (20)–(29):

For air compressor:

$$\dot{E}x_1 + \dot{E}x_{11} - \dot{E}x_2 = \dot{E}x_{D,AC} \tag{20}$$

For combustion chamber:

$$\dot{E}x_2 + \dot{E}x_{2.3} - \dot{E}x_3 = \dot{E}x_{D,CC} \tag{21}$$

For gas turbine:

$$\left(\dot{E}x_3 - \dot{E}x_4\right) - \dot{E}x_7 = \dot{E}x_{D,GT} \tag{22}$$

For exhaust forward duct:

$$\dot{E}x_4 - \dot{E}x_5 = \dot{E}x_{D,EFD} \tag{23}$$

For aft exhaust duct:

$$\dot{E}x_5 - \dot{E}x_6 = \dot{E}x_{D,EAD} \tag{24}$$

For mechanical shaft:

$$\dot{E}x_7 - \dot{E}x_8 = \dot{E}x_{D,GTMS} \tag{25}$$

Work rate distribution:

$$\dot{E}x_{11} = \left(\dot{E}x_8 - \dot{E}x_9\right) \tag{26}$$

For the whole engine:

$$\left(\dot{E}x_1 + \dot{E}x_{2.3}\right) - \dot{E}x_6 = \dot{E}x_{D,ENG} \tag{27}$$

$$\dot{E}x_6 - \dot{E}x_{P,ENG} = \dot{E}x_{L,ENG} \tag{28}$$

$$\dot{E}x_{C,ENG} = \dot{E}x_{L,ENG} + \dot{E}x_{D,ENG} \tag{29}$$

2.7 Exergoeconomic Analysis

The economic analysis, conducted as part of the exergoeconomic analysis, provides the appropriate monetary values associated with the investment, operation, maintenance, and fuel costs of the system being analyzed [7, 8]. These values are used in the cost balances [9].

2.8 Exergoenvironomic Analysis

To minimize the environmental impacts, a primary target is to increase the efficiency of energy conversion processes and, thus, decreases the amount of fuel and the related overall environmental impacts, especially the release of carbon dioxide, which is one of the main components of greenhouse gas [10]. In this study, three steps were applied to carry out the exergoenvironomic analysis of gas turbine system. The first step is the determination of pollutant emission (CO and NO_x) in grams per kilogram of fuel, the estimation of the total cost rate of product and environmental impact and CO_2 emission calculation.

2.9 Determination of Pollutant Emission

In order to determine the pollutant emission in grams per kilogram of the fuel, the adiabatic flame temperature in the combustion chamber has to be computed first. The adiabatic flame temperature in the primary zone;

$$T_{PZ} = A\sigma^{\alpha} \exp\left(\beta(\sigma + \lambda)^2\right)\pi^x\theta^y\psi^z \tag{30}$$

where π is a dimensionless pressure P_2/P_{ref} (P_2 being the combustion pressure and $P_{ref} = 101{,}300$ Pa); θ is a dimensionless temperature T_2/T_{ref} (T_2 being the inlet temperature and $T_{ref} = 298.15$ K); ψ is the H/C atomic ratio ($\psi = 4$); $\sigma = \emptyset$ for $\phi \leq 1$ (ϕ is the fuel to air equivalent ratio), and $\sigma = \phi - 0.7$ for $\phi \geq 1$. Moreover, x, y, and z are quadratic functions of σ based on the following equations [11]:

$$x = a_1 + b_1\sigma + c_1\sigma^2 \tag{31}$$

$$y = a_2 + b_2\sigma + c_2\sigma^2 \tag{32}$$

$$z = a_3 + b_3\sigma + c_3\sigma^2 \tag{33}$$

Table 1 Constant for Eqs. (31)–(33)

	$0.3 < \varphi < 1$		$1 < \varphi < 1.6$	
Constants	$0.92 < \theta < 2$	$2 < \theta < 3.2$	$0.92 < \theta < 2$	$2 < \theta < 3.2$
A	2361.7644	2315.752	916.8261	1246.1778
α	0.1157	−0.0493	0.2885	0.3819
β	−0.9489	−1.1141	0.1456	0.3479
λ	−1.0976	−1.1807	−3.2771	−2.0365
a_1	0.0143	0.0106	0.0311	0.0361
b_1	−0.0553	−0.045	−0.078	−0.085
c_1	0.0526	0.0482	0.0497	0.0517
a_2	0.3955	0.5688	0.0254	0.0097
b_2	−0.4417	−0.55	0.2602	0.502
c_2	0.141	0.1319	−0.1318	−0.2471
a_3	0.0052	0.0108	0.0042	0.017
b_3	−0.1289	−0.1291	−0.1781	−0.1894
c_3	0.0827	0.0848	0.098	0.1037

where parameters A, α, β, λ, a_i, b_i, and c_i are constant parameters. These parameters are given in Table 1 regarding Eqs. (31)–(33) [12]. The calculated exergy rate and other thermodynamic parameters of the components of the TJE are given in Table 2.

The amount of CO and NO_x produced in the combustion chamber and combustion reaction depends on the adiabatic flame temperature [11]. Accordingly, to determine the pollutant emission in grams per kilogram of the fuel were used in this study.

$$\underset{NO_x}{\overset{\bullet}{m}} = \frac{0.15E16\tau^{0,5}\exp(-71,100/T_{PZ})}{P_2^{0.05}(\Delta P_2/P_2)} \quad \underset{CO}{\overset{\bullet}{m}} = \frac{0.719E9\exp(7800/T_{PZ})}{P_2^2\tau(\Delta P_2/P_2)} \tag{34}$$

where τ is the residence time in the combustion zone (τ is assumed constant and is equal to 0.002 s); T_{pz} is the primary zone combustion temperature; P_2 is the combustor inlet pressure; $\Delta P_2/P_2$ is the non-dimensional pressure drop in the combustion chamber.

2.10 Cost of Environmental Impact

The cost of environmental impact expresses the environmental impact as the total pollution damage ($/h) due to CO and NO_x emission by multiplying their respective flow rates by their corresponding unit damage cost (C_{CO}, and C_{NO_x} are equal to 0.02086 $/kgCO and 6.853 $/kg$NO_x$) [8]. In the present work, the cost of pollution damage is considered to be added directly to the expenditures that must be paid.

Table 2 Exergy rate and other thermodynamic parameters of the components of the TJE

	Ex_{in}	Ex_{out}	Ex_{c}	ψ	α	β	χ	ExlP	ExIPR	RExIP	FPR	SI
Component	kW	kW	kW	%	%	%	%	kW	%	%	–	–
AC	2349.56	1664.23	685.33	70.83	10.79	57.51	13.29	199.9	29.17	4.77	1.41	3.43
CC	8013.21	5092.20	2921.01	63.55	46.01	245.11	56.64	1064.78	36.45	25.42	1.57	2.74
GT	2401.66	2349.56	52.10	97.83	0.82	4.37	1.01	1.13	2.17	0.03	1.02	46.10
EFD	2690.53	2643.97	46.56	98.27	0.73	3.91	0.90	0.81	1.73	0.02	1.02	57.79
EAD	2643.97	2597.54	46.44	98.24	0.73	3.90	0.90	0.82	1.76	0.02	1.02	56.94
GTMS	2349.56	2326.22	23.34	99.01	0.37	1.96	0.45	0.23	0.99	0.01	1.01	100.65
Total destruction				3786.78	317.76	73.43		59.64	1270.41	33.55	30.33	
Total loss				1370.47	115	26.57		21.59	459.77	33.55	10.98	
Engine basic	6348.97	1191.72	5157.2	18.77	81.23	432.76	100	4189.22	81.23	100	5.33	1.23
Engine improved	6348.97	2921.91	3427.07	46.02	53.98	117.29	100	1849.87	53.98	44.16	2.17	1.85

Where, Z_k, C_f, C_D, and C_{env} are the purchase cost of each component, fuel cost, cost of exergy destruction, and cost of environmental impact, respectively.

2.11 CO_2 Emissions Calculation

Using the combustion equations, the normalized CO_2 emission is expressed as below [13]:

$$\varepsilon = \frac{m_{CO_2}}{W_{net}} \tag{35}$$

The effect of CO_2 emissions is of considerable significance, such that reduction of its harmful release is twofold. The first is obviously related to communal and environmental health. The second, as suggested in many references, is improvement in reduction of harmful emissions in the combustion chamber can lead to improvements of gas turbine cycle efficiency. Reduction of the harmful emissions in the combustion chamber to the environment has proven its benefits in increasing system efficiency, which in turn increases sustainability by lengthening the lives of the fuel resources. A depletion number Dp could characterize the efficient fuel consumption.

The relationship between the depletion number and the exergy efficiency and SI are described by:

$$\eta_{ex} = 1 - \mathrm{Dp} \quad \mathrm{SI} = \frac{1}{\mathrm{Dp}} \tag{36}$$

3 Results and Discussion

The exergoeconomic parameters considered in this study include average costs per unit of fuel exergy C_F and product exergy C_P, rate of exergy destruction $\dot{E}_D$, cost rate of exergy destruction $\dot{C}_D$, investment and O&M costs rate $\dot{Z}$, and exergoeconomic factor *f*. In analytical terms, the components with the highest value of $\dot{Z}_k + \dot{C}_{Dk}$ are considered the most significant components in terms of an exergoeconomic perspective. This provides a means of determining the level of priority a component should be given with respect to the improving of the system. For all the engines considered, the combustion chamber and air compressor have the highest value of the sum $\dot{Z}_k + \dot{C}_{Dk}$. Therefore, they are the most important components from the exergoeconomic viewpoint. The low value of exergoeconomic factor, *f*, associated with the combustion chamber suggests that the cost rate of exergy destruction is the dominate factor influencing the component. Hence, it is implied that the component efficiency is improved by increasing the capital investment. This can be achieved by increasing gas turbine inlet temperature (GTIT). Table 3 shows the results of exergoenvironmental analysis of this work. The computed exergoenvironmental parameters are CO_2 emission, depletion number, sustainability index, cost flow rate of environmental impacts ($\dot{C}_{\mathrm{env}}$) in \$/h, and total cost rates of products ($\dot{C}_{\mathrm{Tot}}$) in \$/h. The study shows that increasing exergetic efficiency results in CO_2 emission reduction. The increase of exergetic efficiency is related to reduction of ambient inlet air temperature into the

Table 3 Exergy rate and other properties at various system locations for TJE

State	Fluid type	m (kg s^{-1})	p (kPa)	T (K)	c_p (KJ kg^{-1} K^{-1})	Ex (kW)	
0	Air	9.10	99.85	288.15	1.0037	0.00	
1	Air	9.10	99.85	288.15	1.0037	0.00	
2	Air	9.10	389.42	525.65	1.0342	1664.23	
2.3	Fuel (JP-8)	0.14	220.64	298.15		6348.97	
3	Combustion gases	9.24	369.94	1111.67	1.1261	5092.20	
4	Combustion gases	9.24	115.61	942.30	1.0832	2690.53	
5	Combustion gases	9.24	113.30	899.16	1.0822	2646.29	
6	Combustion gases	9.24	111.03	894.70	1.0812	2597.54	
7	Mechanical work					2349.56	
8	Mechanical work					2326.22	
9	Mechanical work					2314.22	
11	CO_2 emissions (kgCO_2/MWh)						112.75
12	Depletion number (Dp)						0.69
13	Sustainability index (SI)						1.23
14	Cost flow rate of env. $\dot{C}_{\mathrm{env}}$ (\$/h) impact						796.54
15	Total cost rates of pr. $\dot{C}_{\mathrm{Tot}}$ (\$/h)						3256.83

compressor. The efficiency of the system is directly linked to the entire system. However, it is apparent that the overall exergy destruction of the cycle decreases, while the sustainability index increases with decreasing compressor inlet temperature.

4 Conclusion

Exergy analysis provides useful information about the performance of the turbojet engine.

- The exergetic efficiency of the engine is accounted for 18.77% with 1191.72 kW as exhaust gases product for thrust.
- The highest exergy destruction between the components of the engine occurs within the combustion chamber with 2921.01 kW, as expected; hence, the combustion reaction is an irreversible process.
- The constructional and thermodynamic improvements on the engine can be made to decrease the exergy destruction and losses rate. After this improvements, the exergetic efficiency increases from 18.77 to 46.02%.
- The results from the exergoeconomic analysis, in common with those from the exergy analysis, show that the combustion chamber has the greatest cost of exergy destruction compared to other components. In addition, the results show that by increasing the turbine inlet temperature (TIT) the gas turbine cost of exergy destruction can be decreased.
- The finding solidifies the concept that the exergy loss in the combustion chamber is associated with the large temperature difference between the flame and the working fluid. Reducing this temperature difference reduces the exergy loss. Furthermore, cooling compressor inlet air allows the compression of more air per cycle, effectively increasing the gas turbine capacity.
- The cost rate of environmental impact is 796.54 $/h.
- The study further shows that increasing exergetic efficiency of gas turbine engine results in CO_2 emissions reduction. The increase of exergetic efficiency is related to reduction of ambient inlet air temperature into the compressor. This implies that improvement of a system's efficiency is twofold. By improving the most inefficient components of the system and utilizing the minimum adequate fuel flow rate ensuring maximum burn. The reduction in wasted unburned fuel and the reduction in overall system inefficiencies results in net CO_2 emissions reduction.

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